Patent Application of

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For

Ins B1 **~~Magnetic Recording~~ Head Burnishing ~~Method~~**

BACKGROUND OF INVENTION

The continuous development of magnetic recording disk drives results in ever increasing data storage densities in the storing layers. To read and write the magnetic signals, the read and write heads have to be kept in ever-closer distance to the rotating disc surface where the storing layers are deposited.

The read and write heads are typically integrated in the so-called sliders, which provide specifically designed three-dimensional features on their bottom side that is next to the disk surface. These three-dimensional features utilize the viscosity and kinetic energy of a rotating air stream induced by the spinning disk to lift the sliders on a predetermined fly height during the hard disk operation.

The viscosity of the air stream depends mainly on the air temperature and the air pressure.
The kinetic energy of the rotating air stream depends on its velocity relative to the slider and subsequently on the rotational speed of the hard disk.

The bottom side performs the function of an air bearing in closest proximity to the disk surface. As a result fly heights in the nanometer range can be implemented.

Such small fly heights require high precision of the disk surface since even the smallest surface inconsistencies result in a contacting of the slider with the fast moving disk surface. Even though the utilized fabrication processes provide for sufficient surface evenness of the hard disk, special wear-in procedures are commonly performed to eliminate eventual and/or recognized surface unevenness. These wear-in procedures are typically performed by reducing the fly height below the operational level and moving the slider over the surface until no contacting is recognized anymore. The slider, which is made of a relatively hard material is thereby utilized as an abrasive tool to remove any interfering surface inconsistencies from the relatively soft top layers of the hard disk.
The fly height is typically reduced by changing the rotational speed of the hard disk and/or by changing the air pressure.

A number of U.S. Patents discloses variations of the hard disk wear-in procedure, which is commonly referred to as burnishing.

U.S. Pat. No. 5,696,643 and U.S. Pat. No. 5,863,237, for instance, describe methods to burnish away topographic irregularities from the disk surface. After recognizing an surface irregularity via a thermal contacting signal, the rotational speed of the hard disk is reduced and the fly height of the read/write head is lowered. The burnishing is performed over a certain time period, during which the height of the surface irregularities is continuously reduced. After finishing the disk burnishing the interference signals no longer occur during operational rotation of the hard disk.

Japanese Patent JP 06309636 describes a similar burnishing method, except that the read/write head is lowered by reducing the air pressure under which the hard disk drive operates.

The thermal contacting signal results from a dynamic resistance change in the read head, which is thermally induced by the frictional energy created during the contacting of the head.

The dynamic resistance change itself may be recognized with various methods. In one method, it is recognized during the regular read operation of the hard disk. This requires a fully functioning hard disk drive, including a partitioned hard disk. U.S. Pat. No. 5,751,510 describes such a method.

In another method, the dynamic resistance change is obtained by the read/write head without reading any data from the hard disk. In such a case, an electrical stimulus voltage is applied to the read head. This method can be performed at an earlier hard disk fabrication stage since it does not require operational data read from the hard disk surface. A calibration signal and/or a calibration value has to be obtained for a known non-interference condition. U.S. Pat. No. 5,806,978, for instance, describes such a method.

With continuously decreasing fly heights a contacting and non-contacting operational conditions in the head/disk interface become less and distinctly able. Read/write heads operate typically with their air bearing surface in an angulated orientation relative to the disk surface. The microscopic air bearing features are typically fabricated with a common protrusion direction normal to the substrate plane, which results in essentially coplanar surfaces and linear edges. The design of the air bearing surface defines the primary contacting edge, which initially contacts the moving disk surface. In the case where the front portion of the air bearing surface is raised sufficiently, the primary contacting edge becomes the front edge with the read and write elements. In such a case, the contacting of the slider during the regular hard disk operation occurs mainly with the slider front edge.

The linear contacting of the slider with the primary contacting edge results in relatively high surface pressures, which result in wear of the disk surface and/or the slider. As a result of disk wear, debris may

adhesively build up on the primary contacting edge. Since it is desirable to have the read/write heads in closest proximity to the disk surface, they are preferably in an area adjacent to the primary contacting edge. Debris built-up alters the read and write characteristic of the heads and needs to be prevented. U.S. Pat. No. 6,088,199, for instance, discloses an abrasive section placed on the hard disk to remove eventual debris built-up on the slider. The patent does not prevent debris from building up, however. It provides only a cleaning method.

Wear in the head/disk interface related to operational slider contact is explored in a number of scientific disclosures.
In IEEE Trans. Magn. (USA) vol 34, no.4, pt.1, p. 1714-16, a conference/journal paper is disclosed, which describes the abrasive wear and adhesion of the slider surface.
In the 1996 AME/STLE Tribology Conference (TRIB-Vol.6) p.17-23, a conference paper is disclosed, which describes new techniques for evaluating slider wear and burnishing of the head/disk interface.
Further, in the Proceedings of the SPIE - The International Society of Optical Engineering (USA) vol.2604 p.236-43, contact force measurements at the head/disk interface for contact recording heads in magnetic recording are disclosed and correlated to the burnishing in the head/disk interface.
Finally, in the Journal of Materials Research vol.8, no.7 p. 1611-28, friction and wear studies of silicon in sliding contact with thin-film magnetic rigid disks are disclosed.

The ever decreasing fly heights make the limitations described in the above scientific paper increasingly stringent.

The present invention addresses these limitations and provides a solution for them.

OBJECTS AND ADVANTAGES

It is a primary object of the present invention to provide a slider head in a wear reducing configuration and a method for creating the same.

It is another object of the present invention to provide a method for creating the wear-reducing configuration with feasible fabrication effort.

SUMMARY

A slider burnishing method is introduced, in which a primary contacting area of the slider is flattened in an abrasive way.

The primary contacting area is defined by the operational orientation of the slider relative to the hard disk surface. In the case of a planar slider, the contacting area is essentially a contacting edge at the front end of the slider where the read and write heads are located.

There are techniques known to those skilled in the art that apply a bending in the form of a crown and/or camber to the air bearing surface. The bending of the air bearing

surface results in a smoother contacting of the air bearing surface with the hard disk surface. In such a case the contacting area may be at a more central location of the slider adjacent to the location of the read and write heads.

The abrasive flattening of the contacting area is accomplished by applying a slider burnishing method during which the slider is kept in contact with the rotating hard disk. The slider burnishing method is designed for:

- preventing damage of the relatively soft surface layers of the hard disk;
- preventing debris accumulation in the contacting area during the slider burnishing;
- keeping the thermal rise in the slider below a critical maximum; and
- creating a predetermined flattened area.

The slider burnishing creates a flattened area that is planar and essentially parallel to the hard disk surface. An eventual contacting of the slider with the hard disk surface results in reduced surface pressure in the contacting area, which is commonly referred to as the head/disk interface. The slider contacting may either be intermediate or permanent.
Under operational conditions where a fly height needs to be maintained, the flattened area defines, together with the hard disk surface, an even air bearing gap. This air bearing gap enhances the aerodynamic properties of the air bearing surface, such that smaller fly heights can be utilized in a stable fashion.

The slider burnishing method consists of a number of individual steps with various contacting forces and rotational disk speeds. The main steps perform the following tasks:

- preparing the hard disk surface by removing eventual topographic inconsistencies;
- burnishing the slider; and
- checking the burnishing result.

In an alternate embodiment the slider burnishing process is mainly performed by the following steps:

- deriving a resistive reference signal during a non-contacting condition of the slider.
- preparing the hard disk surface by removing eventual topographic inconsistencies;
- burnishing the slider;
- checking the burnishing result; and
- sweeping the disk surface to remove debris.

The calibration signal is derived prior to the slider burnishing, to have a reference value so as to determine the contacting signal. Calibration signal and contacting signal are a function of the read head resistance, which influences a bias voltage applied to the read head during the slider burnishing. The read head resistance is dependent on the read head temperature and changes during frictional contact with the disk surface, as is known to those skilled in the art.

The contacting signal is utilized to observe the contacting characteristic during the following steps of the slider burnishing method.

During the disk surface preparation the fly height is consecutively lowered in correspondence with a reduction of the rotational disk speed. Topographic inconsistencies are thereby removed without creating abrasive deposits on the contacting area.

The slider burnishing is the most time consuming step of the slider burnishing method and is performed with a predetermined contacting force at a relatively low rotational speed. Since the disk surface has been smoothened sufficiently a permanent slider contact can be maintained without the risk of vibrations and/or excessive abrasion induced by eventual topographic inconsistencies. During the slider burnishing, the slider is continuously moved over the rotating disk surface to prevent local thermal rise in the disk surface. Rotational speed and contacting force are also selected to keep thermal rise of the slider below a critical level at which the heat sensitive components of the slider may be damaged and/or debris may weld on the contacting area.

During the clearance check the fly height is raised to a level at which no contacting signal is recognized anymore.

The final sweeping step removes any debris accumulated on the disk surface during the prior burnishing operation.

The slider burnishing method is performed with various rotational speeds and independently defined fly heights and/or contact forces between the slider and the hard disk surface. To adjust the fly heights and/or the contact forces in an independent fashion to the rotational speeds, the air pressure under which the slider burnishing is performed is correspondingly adjusted.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 shows a three-dimensional view of a simplified hard disk drive with a removed housing portion such that a hard disk and a slider attached on a slider arm are visible.

Fig. 2 shows an enlarged detailed view of the interface between the slider and the hard disk of **Fig. 1** in a direction perpendicular to a reference plane also shown in **Fig. 1**.

Fig. 3 shows a simplified slider with an essentially planar adaptation surface.

Fig. 4 shows a simplified slider with a first curved adaptation surface having a curvature axis that is collinear with a symmetric plane of the slider.

Fig. 5 shows a simplified slider with a second curved adaptation surface having a curvature axis that is perpendicular to a symmetric plane of the slider.

Fig. 6 shows a simplified slider with a third curved adaptation surface having the first and second curvature axes.

Fig. 7 shows a simplified graph of a control signal change during the slider burnishing process for an exemplary case where the control signal sensor is within the burnishing area.

Fig. 8 shows a simplified graph of a control signal change during the slider burnishing process for an exemplary case where the control signal sensor is outside the burnishing area.

Fig. 9 shows a block diagram of a preferred embodiment of a burnishing method.

Fig. 10 shows a block diagram of an alternate embodiment of the burnishing method.

Fig. 11 shows a graph of four exemplary control signal voltages of four different sliders during their burnishing process.

Fig. 12 shows a graph of four relative resistance changes of read heads operating as contacting sensors during the burnishing process of the four sliders referred to in **Fig. 11**.

DETAILED DESCRIPTION

Although the following detailed description contains many specifics for the purposes of illustration, anyone of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the following preferred embodiment of the invention is set forth without any loss of generality to, and without imposing limitations upon, the claimed invention.

Fig. 1 shows the a simplified hard disk drive **HDD** with the main operational components involved in the slider burnishing being visible through a removed housing portion of the hard disk drive **HDD**. A slider **1** is attached to a slider arm **1C**, which pivots around a slider arm axis **1D**. The slider has a front face **1B** and a symmetric plane **1F**. **Fig. 1** also shows a hard disk **2** having a hard disk surface **2A** and a spinning axis **2B**. During the slider burnishing, the slider arm **1C** pivots around the slider arm axis **1D** such that the slider **1** performs centripetal and centrifugal movements along the hard disk surface **2A** of the spinning hard disk **2**. Dependent on the velocity of the centripetal and centrifugal slider movements relative to the rotational speed of the hard disk surface, the symmetric plane **1F** defines a movement angle together with the resulting movement vector in the interface between the slider **1** and the hard disk surface **2A**. In the case where the slider arm **1C** does not move, the movement angle is approximately zero. It is clear to one skilled in the art how the geometric and

dynamic conditions of the hard disk **2** and the slider arm **1C** precisely define the movement angle.

Fig. 2 shows an enlarged view of the interface between the slider **1** and the hard disk **2** in a direction perpendicular to the reference plane **1F**. The main physical characterizing elements of the present invention in the slider/disk interface are:

- the hard disk surface **2A**;
- adaptation surfaces **1E, 11E, 12E, 13A** (see **Figs. 3-6**);
- front faces **1B, 11B, 12B, 13B** (see **Figs. 3-6**);
- burnishing areas **1A, 11A, 12A, 13A** (see **Figs. 3-6**); and
- burnishing sensors **1R, 11R, 12R, 13R** (see **Figs. 3-6**).

The front faces **1B, 11-13B** are shown in planar configuration for the purposes of general understanding. It is noted that front faces of sliders may have any shape without affecting the core of the invention.

For general understanding, the introductory example described in **Fig. 2** refers to the slider **1** having a planar adaptation surface **1E** perpendicular to the symmetric plane **1F**. The adaptation surface **1E** is oriented with an adaptation angle **3A** relative to the hard disk surface. In the preferred embodiment of the invention, the adaptation angle **3A** is essentially identical with an operational angle (not shown) under which the adaptation surface **1E** will be kept in position during the operational use of the hard disk drive.

The core of the invention also applies to a case where the adaptation angle **3A** is different from the operational angle.

During the slider burnishing a contacting condition is provided between the adaptation surface **1E** and the hard disk surface **2A**, which results in a burnishing area **1A** abrasively formed by the hard disk surface **2A**. In the preferred embodiment the contacting condition is provided by altering dynamic and/or static fluid properties that influence a fly height of the slider **1** above the hard disk surface **2A**, as is known to those skilled in the art. The dynamic fluid properties are, for instance, altered by changing the rotational speed of the hard disk **2**, such that the velocity of a concentrically circulating fluid stream is reduced.

The static fluid properties are, for instance, altered by changing the fluid viscosity, for instance, by reducing the static pressure of a compressible fluid.

The fluid utilized for the slider burnishing may be identical to/or different from the operational fluid under which the hard disk drive is operated. In the preferred embodiment the burnishing fluid is air.

It is noted that the burnishing fluid may be any gaseous or liquid material that is suitable for providing the contacting characteristic. The preferred gaseous burnishing fluid is air. Alternate gaseous burnishing fluids may be, for instance He, or Ne, which may introduce a reduced fly height due to their low viscosity relative to the viscosity of the operational fluid in the preferred form of air. In general, the fly height may be adjusted during the burnishing process by altering the composition

of the burnishing fluid and consequently the viscosity relative to the composition of the operating fluid. The operating fluid is the fluid, which fills the space between the slider and the disk surface during the operational use of the hard disk. In addition, the inert nature of He and Ne protect the slider and disk surface against oxidation, which may result from the elevated temperatures in the burnishing interface between slider and disk surface.

In addition, any burnishing enhancing material may be applied to the hard disk surface **2A** and/or the adaptation surface **1E, 11-13E** to enhance the slider burnishing process. In particular, slider burnishing enhancing materials that overcome the limitations imposed by the operational softness of the hard disk surface **2A** relative to the operational hardness of the adaptation surface **1E** may be applied to the hard disk surface **2A** prior to the slider burnishing process. This burnishing enhancing material may be applied in a fashion that corresponds to the burnishing process such that at the end of the burnishing process the burnishing enhancing material itself is abraded and no longer present on the hard disk surface **2A**.

During the slider burnishing process, material is removed from the slider **1**. The removed material **1G** leaves a burnished area **1A** behind. The removal material height **3B** defines, together with slider shape, the removed material volume. The removed material volume influences the slider burnishing time. To keep the slider burnishing time to a minimum the contacting characteristic has preferably a contact force gradient that corresponds to the increase of burnishing area during the slider burnishing. As a result, the contact pressure in the slider/disk interface remains

constant and below a critical level. The critical pressure level is defined by the abrasion resistance of the hard disk surface **2A** and the thermal drain capacity of the slider.

The adaptation angle **3A** influences a fly characteristic of the slider **1** above the hard disk surface **2A**. The fly characteristic keeps the slider **1** in a predetermined fly height range under operational conditions as is known to those skilled in the art. The burnished areas **1A, 11-13A** define, together with the hard disk surface **2A**, an operational gap that has stabilizing influence on the fly characteristic. In the preferred embodiment where the adaptation angle **3A** is essentially equal to the operational angle the operational gap has a consistent width. As a result, the fluid stream in the gap has a constant velocity resulting in a balanced fluid pressure in the gap. In case of a contacting of the slider **1** with the hard disk surface **2A**, the burnished areas **1A, 11-13A** contact snuggly with the hard disk surface **2A**, which avoids unfavorable abrasion of the hard disk surface **2A**.

In **Figs. 3-6** a number of configurations of the sliders **1, 11-13** is shown. The configurations of the sliders **1, 11-13** are shown with the adaptation surfaces **1E, 11-13E**, the contacting sensors in the preferred form of data read heads **1R, 11-13R**, write heads **1W, 11-13W**, the burnished areas **1A, 11-13A** and the front faces **1B, 11-13B**.

The sliders **1, 11** of **Figs. 3** and **4** have their data read heads **1R** and **11R** within the burnished area **1A, 11A**.

The sliders **12, 13** of **Figs. 5** and **6** have their data read heads **12R** and **13R** outside the burnished area **12A, 13A.**

In **Fig. 4,** the adaptation surface **11E** has a curvature with a curvature axis **11F.** The curvature of the adaptation surface **11E** is known to those skilled in the art as camber.

In **Fig. 5,** the adaptation surface **12E** has a curvature with curvature axis **12F.** The curvature of the adaptation surface **12E** is known to those skilled in the art as crown.

In **Fig. 6,** the adaptation surface **13E** has a curvature with a curvature axes **13F** and **13G.** The curvature of the adaptation surface **13E** is a combination of crown and camber.

For the exemplary sliders **1, 11** the adaptation angle **3A** remains constant during the slider burnishing process. For the exemplary sliders **12, 13** the adaptation angle **3A** increases during the slider burnishing process.

At the start of the slider burnishing the sliders **1, 11-13** have initial burnishing contacts with the hard disk surface **2A.** At the initial burnishing contacts the burnishing areas **1A, 11-13A** start to form and to expand. For the slider **1,** the initial burnishing contact is an edge of the front face **1B** and the adaptation surface **1E.** For the slider **11,** the initial burnishing contact is a point on the edge of the front face **2B** and the adaptation surface **2E.** For the slider **12,** the initial burnishing contact is a initial contacting line parallel to the curvature axis **12F.**

The distance of the initial contacting line to the data read head **12R** depends on the overall orientation of the slider **12** to the hard disk surface **2A**.

For the slider **13**, the initial burnishing contact is an initial contacting point. The distance of the initial contacting point to the data read head **13R** depends on the overall orientation of the slider **13** to the hard disk surface **2A**.

The burnishing areas **1A**, **12A** have a first extension direction essentially perpendicular to the front faces **1B** and **11B**.

Since the sliders **1**, **11-13** are shown with final fabricated burnishing areas **1A**, **11-13A**, the initial burnishing contacts are no longer present and therefore not shown.

During the slider burnishing of the slider **1**, the burnishing area **1A** expands away form the edge between the front face **1B** and the adaptation surface **1E**. As shown for the slider **1**, the burnishing area **1A** expands beyond the data read head **1R** and the write head **1W**.

During the slider burnishing of the slider **11**, the burnishing area **11A** expands away form the initial contacting point on the edge between the front face **2B** and the adaptation surface **2E**. As shown for the slider **11**, the burnishing area **11A** expands beyond the data read head **11R** and the write head **11W**.

During the slider burnishing of the slider **12**, the burnishing area **12A** expands away form the initial contacting line. As shown for the slider **12**, the initial contacting line is at a distance to the data read head **12R**, such that the final expanded burnishing area **12A** does not overlap with the data read head **12R** and the write head **12W**.

During the slider burnishing of the slider **13**, the burnishing area **13A** expands away form the initial contacting point. As shown for the slider **13**, the initial contacting point is in a distance to the data read head **13R** such that the final expanded burnishing area **13A** does not overlap with the data read head **13R** and the write head **13W**. It is clear to one skilled in the art that the configurations of the sliders **1, 11-13** may be defined such that the burnishing areas **1A, 11-13A** may or may not overlap with the data read heads **1R, 11-13R**.

It is clear to one skilled in the art that the adaptation surfaces **1E, 11-13E** may have any shape or configuration. Furthermore, the adaptation surfaces **1E, 11-13E** may form an air bearing surface at is known to those skilled in the art, and/or may be a component of an air bearing surface.

The slider burnishing process is monitored by use of a contacting sensor. In the preferred embodiment the contacting sensors are the data read heads **1R, 11-13R** as they are known to those skilled in the art for the recognition of disk surface contact recognition. In the preferred embodiment the natural resistance of the data read heads **1R, 11-13R** is recognized prior to the slider burnishing process and utilized as a reference value. During the slider burnishing a dynamic and static resistance changes may occur in the data read heads **1R, 11-13R**.

A dynamic resistance change is mainly induced by a thermal friction energy resulting from a disk surface contacting of

the contacting sensors and/or surrounding areas of the sliders **1, 11-13**.

A static resistance change is mainly induced in a case where the contacting sensors are or become part of the burnishing area during the slider burnishing as it is shown with the sliders **1, 11**. The removing of material **1G** includes a removing of the contacting sensor material, which results in a static resistance change of the contacting sensor.

In **Fig. 7** a simplified graph shows a curve **22A** representing the static resistance change and a curve **22D** representing the dynamic resistance change for a case where the data read heads **1R, 11-13R** are overlapped by the burnishing areas **1A, 11-13A**.

The vertical axis **20** (see also **Fig. 8**) represents the resistance change relative to the total read head resistance. The horizontal axis **21, 31, 41** (see **Figs. 8, 11, 12**) represent a number of burnishing cycles during which the sliders **1, 11-13** are moved back and forth on the disk surface **2A**.

Prior to the slider burnishing, a reference value **22R, 23R, 32R** and **42R** (see also **Figs. 8, 11, 12**) is recognized preferably on a slider position for which a non-contacting condition is secured. Such a slider referencing position is preferably on a parking ramp where the slider arm **1C** is parked during non-operation of the hard disk drive.

The curve **22A** has an initial incline angle and becomes flatter during the slider burnishing. The curve **22A** approaches asymptotically to a theoretical maximum line

22E. The incline angle of the curve **22A** over its length corresponds to the increasing removed material height **3B**. The burnishing areas **1A, 11-13A** start to form from a contacting line or a contacting point, such that a relatively low amount of initially removed material **1G** results in a relatively high gain of removed material height **3B**.

With continuing material removal the burnishing areas **1A, 11-13A** extend. As a result, for a given amount of removed material the gain of removed material height **3B** becomes ever smaller. The increase of the burnishing areas **1A, 11-13A** also results in a reduced contacting pressure for a given contacting force. Since the contacting force is limited to prevent thermally induced damages to the disk surface **2A** and/or the sliders **1, 11-13**, the contacting pressure reaches a level at which abrasion of the slider material no longer occurs. The material properties of the sliders **1, 11-13**, the abrasive properties of the hard disk surface **2A** and the maximum contacting force define a theoretical maximal burnishing area extension, which is recognized by the theoretical maximum line **22E**.

In **Fig. 8** the curve **23A** corresponds to the curve **22A**, except for the case where the contacting sensors do not become overlapped by the burnishing areas **1A, 11-13A**. Hence, the contacting sensors, e.g. the data read heads **1R, 11-13R**, are not exposed to the material removal process. Consequently, the data read heads **1R, 11-13R** do not change their static resistance, and the curve **23A** is horizontal.

The curves **22D, 23D** (see **Fig. 8**) provide examples for the dynamic resistance change during the slider burnishing. After recognizing the reference resistance **22R, 23R, 32R, 42R** the slider burnishing process is initiated by bringing the sliders **1, 11-13** into contact with the rotating disk surface **2A**. Initially, the dynamic resistance change has a relatively volatile nature. The reason for this is topographic inconsistencies in the hard disk surface that impose varying contacting conditions. During the slider burnishing these topographic inconsistencies are removed and the dynamic resistance change becomes smaller and smaller. This is shown in **Figs. 7** and **8** by the upper boundary curves **22C, 23C** and the lower boundary curves **22B** and **23B**.

It is noted that the contacting sensor may be any device known to those skilled in the art to recognize the contacting characteristic. The contacting sensor may or may not utilize a reference signal.

It is further noted that the reference signal may be a predetermined signal derived independently from the hard disk drive subject to the slider burnishing. The reference signal may be statistically, empirically, or theoretically predetermined.

The slider burnishing is performed by a burnishing method in which the burnishing parameters are variously specified such that distinctive slider burnishing steps are created.

Fig. 9 shows a block diagram of the steps of a burnishing method of the preferred embodiment. The burnishing method

begins with preparing the hard disk surface, followed by burnishing the slider and finally checking the burnishing result.

During the preparation of the hard disk surface **2A**, the sliders **1, 11-13** are continuously lowered, preferably by changing the rotational speed of the hard disk **2** and/or by reducing the environment pressure. The lowering may be performed either in a predetermined fashion, or in correspondence with recognized dynamic resistance fluctuations. Dynamic resistance fluctuations indicate the contacting dynamic. In other words, it is important to prevent the sliders **1, 11-13** from vibrating and from shifting their pitch angles to a negative value when hitting topographic inconsistencies. Topographic inconsistencies may be bumps, waves or the like on the hard disk surface **2A** as known to those skilled in the art. The pitch angle corresponds to the adaptation angle **3A**. A negative pitch angle would cause the slider to plow into the hard disk surface **2A**. This needs to be prevented at any cost.

Once the dynamic resistance fluctuations have reached a minimal level indicating a required planarity and/or smoothness of the hard disk surface **2A**, the burnishing parameters are adjusted to levels that create a contacting characteristic primary defined to perform the slider burnishing. The slider burnishing step may be initiated by recognizing the dynamic resistance fluctuations and/or after a predetermined surface preparation period.

Following the slider burnishing step, the hard disk drive is brought into operational mode, which includes, for instance, the adjustment of the environment pressure and/or the adjustment of the hard disk speed to operational levels. The contacting sensor recognizes then the actual fly height achieved by fabricating the predetermined burnishing areas **1A, 11-13A**.

Fig. 10 shows a block diagram of the preferred embodiment with the additional steps of deriving a resistive reference signal during a non-contacting condition of the slider and sweeping the disk surface to remove debris.
The resistive reference signal may be the natural resistance of a resistive contacting sensor like, in the preferred embodiment, a magnetic read head as is known to those skilled in the art.
The sweeping of the disk surface **2A** may be performed with a sequence of centrifugal slider movements in disk contact alternating with centripetal slider movements without disk contact. Disk contacting and non-contacting may be provided, for instance, by changing the rotational speed of the hard disk **2** or the environment pressure.

In the case where the resistive reference signal is utilized, the checking of the burnishing result is performed by comparing an operational resistive signal of the contacting sensor derived under operational conditions of the hard disk drive. A non-contacting operation of the sliders **1, 11-13** at a fly height that is accomplished by the defined burnishing areas **1A, 11-13A** is established when the operational resistive signal is within a specified range of the resistive reference signal.

Fig. 11 shows four curves **34A-D**, each having one of the line styles **33**. The vertical axis **30** represents a voltage level of the contacting signal in the approximate occurring range during the burnishing method. The four curves **34A-D** are derived from experimental slider burnishing performed on sliders that are different from those described in the above. The four curves **34A-D** are shown for the sole purpose of general understanding without any claim of accuracy. The four curves **34A-D** are integrated from a filtered measured signal and correspond to the simplified curve **22D**. The filtered measured signal is cleared of electronic noise and other high and low frequencies, which do not relate to the burnishing process.

The burnishing method is applied during the period **31A** (see also **Fig. 12**). The preparation of the slider surface is performed during the period **31B** (see also **Fig. 12**). The slider burnishing is performed during the period **31C** (see also **Fig. 12**).

During the period **31B** the voltage level has strong fluctuations as explained above. Towards the end of the period **31B** the voltage level change becomes more steady, which indicates the successful preparation of the hard disk surface **2**. When the burnishing parameters are changed according to the requirements for the slider burnishing, the voltage level has again strong fluctuations for a short period **31E**. This indicates that hit clearance is not obtained yet, which means that the slider is still hitting the disk surface.

During the period **31D** at the end of the slider burnishing process, the rotational speed of burnished hard disk is gradually increased again and the regular operational

conditions are established. An operational voltage signal **32I** is derived. The operational voltage signal **32I** has a level discrepancy **31F** to a reference voltage signal **32R** that indicates a predetermined clearance increase and the successful slider burnishing as described above.

Fig. 12 shows four curves **44A-D,** each having one of the line styles **44.** The vertical axis **40** represents the static resistance change relative to the total resistance in magnetic read heads that are utilized as contacting sensors.

The four curves **44A-D** are derived during the same experimental slider burnishing as described in **Fig. 11.** The four curves **44A-D** are shown for the sole purpose of general understanding without any claim of accuracy.

The fluctuating static resistance change at the begin of the period **31B** results from the disk surface preparation, during which also the slider is exposed to a certain abrasion.

Once the topographic inconsistencies are removed, the relative static resistance change goes into a steady incline. During the change from the disk preparation step to the slider burnishing step the curves **44A-D** have a short inconsistency as described in **Fig. 11.** During the period **31C** the tangential angle of the four curves **44A-D** goes towards zero, which indicates that the maximum burnishing areas are reached. The curves **44A-D** are practically obtained curves that correspond to the simplified curve **22A.**

It is noted that the disk surface preparation may be optionally and eventually initiated after performing a disk surface verification process in which the evenness of the hard disk surface is recognized. The verification process may be performed by lowering the sliders **1, 11-13** and recognizing the magnitude of the contacting signal fluctuations to derive information about the topographic inconsistencies. The verification process may be performed only for a relatively short period compared to the surface preparation process, since it does not perform a fabrication but only a measurement.

Accordingly, the scope of the invention described in the specification above is set forth by the following claims and their legal equivalent: